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Effects of the Abrasiveness of Test and Training Site Soils on Parachute Life

Austin W. Hogan

May 1992

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Special Report 92-11

U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Effects of the Abrasiveness of Test and Training Site Soils on Parachute Life

Austin W. Hogan

May 1992

Prepared for
U.S. ARMY NATICK RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

PREFACE

This report was prepared by Dr. Austin W. Hogan, Research Physical Scientist, Geochemical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the Parachute Engineering Branch, Airdrop Systems Division, Aero-Mechanical Engineering Directorate, U.S. Army Natick Research, Development and Engineering Center.

The author thanks Susan Taylor for her contributions to this work. Technical review was provided by Dr. L. Peck and E. Chamberlain, both of CRREL.

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EXECUTIVE SUMMARY

Soil specimens from seven paratroop training drop zones, two cargo chute test areas and a test pit at the U.S. Army Natick Research, Development and Engineering Center were analyzed to examine the possible relationship between physical properties of the soil and abrasion of parachute materials. Also analyzed was soil retained within the braid and core of parachute cord test specimens and test plates exposed to the environment near riggers' tables at troop training sites.

The size distribution and clay mineralogy of the specimens were quite different. Surface materials from the Saudi and Israeli deserts approached spherical symmetry, while surface materials from test sites at China Lake and Yuma Proving Ground were quite angular. There is a great difference in the mass fraction of fines among the several samples but all contain material in the size range passing the 0.125-mm sieve.

Several parachute lines that had previously been strained and exposed to local soil material in the Natick test pit were examined for soil residue. The fine fraction of soil penetrated the coreless braid, and the smallest particles present were retained within the strands of the braid. Fine particles were found between fibers of core strands subjected a single test drop, although the surface of the exterior braid looked clean.

Individual soil particles caused abrasive damage to delrin test plates in a simple sliding friction test; this damage was related to particle size. A more specific experiment is necessary to examine the abrasion of textile strands by the smallest size fraction of the soil material. I propose that a microscopic method of measuring soil particle hardness by relating size-classified soil particles to Mohs hardness standards be used to provide a numerical index of soil abrasion. This experiment may also determine if processes analogous to "work hardening" cause fine particles to be harder than the antecedent material.

Effects of the Abrasiveness of Test and Training Site Soils on Parachute Life

AUSTIN W. HOGAN

INTRODUCTION

The failure of individual parachutes, as a function of service life and exposure, has long been of interest to the U.S. Army (Coskren and Wuester 1989). Examination of a sampling of parachutes used by the U.S. Army and the U.S. Forest Service "Smokejumpers" indicates that suspension lines begin to degrade during the first 30 uses. Laboratory tests by Rodier et al. (1989) confirmed that suspension line degradation is the most common way that parachutes fail, and that this degradation is primarily a result of the accumulation of grit within the suspension lines. They also concluded that inherent geological differences in soil properties would alter the service life of personnel parachutes deployed in varying geographic locales.

This report describes the physical properties of surface soil samples collected in varying locales, at established drop zones, maneuver areas, test centers and from the test pit used by Rodier et al. (1989). Table 1 presents the soil specimens provided for analysis. Representative specimens were collected from the surface, sealed in plastic bags and transported to the laboratory.

ANALYSIS OF SPECIMENS

Bulk analysis and size partitioning

All specimens except 10/28VI91 were received in multiple sealed plastic bags, labeled as to origin. All were received in a relatively dry state and in very good condition. The specimens will be referred to by source location and the first two digits of the identifying code throughout the report—for example "Sicily (04)" corresponds to specimen 04/17VI91.

A working quantity (10 to 20 g) of each specimen was transferred to a 15-cm-diameter Petri dish, and the remaining bulk sample resealed. Each sample was leveled by vibration of the dish, and visually inspected. A few bits of organic matter and small gravel grains were removed from some of the samples.

A gross microscopic examination was made of each specimen, using a Nikon stereo microscope and incident tungsten illumination, to determine particle size and shape characteristics. A 10- × 10-cm glass slide was coated with GE silicon contact cement and placed atop the soil specimen, with the contact cement facing downward; the particle bed

Table 1. Identification of surface soil specimens.*

ID code		*Collection location*
01/14VI91†	Philips Drop Zone	Yuma Proving Ground, Arizona
02/14VI91	G4 test area	NWC, China Lake, California
03/14VI91	Test pit	NRDEC, Natick, Massachusetts
04/17VI91	Sicily drop zone	Fort Bragg, North Carolina
05/17VI91	Holland drop zone	Fort Bragg, North Carolina
06/17VI91	Normandy drop zone	Fort Bragg, North Carolina
07/17VI91	Dhahran/Riyadh Highway	Saudi Arabia
08/27VI91	Special Forces drop zone	Camp Blanding, Florida
09/27VI91	Frazer drop zone	Fort Benning, Georgia
10/28VI91	From coreless braid	NRDEC, Natick, Massachusetts
11/25VII91	Drop zone south of Tel Aviv	Israel

* Specimens were collected by research coordinators and other members of the NRDEC community for E. Wuester, and provided to CRREL by him during June 1991.

† Number of sample/ date examined; precise points of collection are not known.

was then vibrated by tapping the Petri dish. The silicon cement coating is quite thin relative to the size of the particles, and a monolayer of particles can be fixed (Hogan 1972) on the slide in this manner.

The stereo microscopy of these mounts showed great differences in the gross properties of the specimens. Particles from Yuma (01), China Lake (02) and Natick (03) were quite angular, varied considerably in size and were extremely different from those from Saudi Arabia (07) and Israel (11), which approached sphericity and had most of the particles confined to a narrow size range. The materials from three drop zones at Fort Bragg (04, 05, 06) are strikingly different in appearance. The microscopic analysis showed that this difference was caused by the presence of varying quantities of much smaller, red-pigmented particles on the surface of the more plentiful crystalline particles.

A sample of 5 to 10 g of soil was taken from each Petri dish containing specimens for gross size partitioning. These samples were collected by extracting two volumes with a spatula along two orthogonal lines crossing the full particle bed in each dish. Each sample was weighed with milligram precision, and sorted according to a DIN Prufsieb micro-sieve series. The portions of each sample retained in each sieve were weighed and transferred to individual vials and the fraction of each specimen passing the 0.25-mm stage but retained by the 0.125-mm stage was resieved, reweighed and combined with the initial cut fractions in the proper size class. The fraction of particles retained by the 1.0-mm sieve was withdrawn and received no additional analysis.

The relative mass fraction in each size cut is determined versus the total mass passing the 1-mm sieve. The mass size distributions passing the 1-mm DIN Prufsieb sieve for each specimen are tabulated in Table 2. Additional graphical presentations of particle size distribution are presented in Appendix A. The four separations of particles passing the 1-mm sieve were generally homogeneous in appearance. The Camp Blanding (08) specimen contained few fines, but contained a relatively large amount of noticeably darker material. An additional microscope mount was prepared from each fraction passing the 0.125-mm sieve stage for optical size analysis.

The data in Table 2 indicate that the Yuma Proving Ground and China Lake Test Center specimens contain the greatest mass fraction of particles passing the DIN Prufsieb sieve series. This may be associated with the location of China Lake

Table 2. DIN Prufseib sieve series partition of soil specimens.

Location	*1.0<D>0.5*	*0.5<D>0.25*	*0.25<D>0.125*	*Passes 0.125 mm*
01 Yuma	0.075	0.243	0.374	0.308
02 China Lake	0.064	0.117	0.383	0.437
03 Natick TP	0.156	0.235	0.338	0.271
04 Sicily	0.179	0.376	0.320	0.125
05 Holland	0.172	0.311	0.434	0.193
06 Normandy	0.029	0.364	0.407	0.199
07 Saudi Arabia	0.003	0.038	0.793	0.165
08 Blanding	0.050	0.376	0.456	0.118
09 Benning	0.092	0.243	0.480	0.184
10 Braid (Natick)	0.003	0.005	0.183	0.819
11 Israel	0.019	0.121	0.832	0.029

in a playa deposit, and the Yuma drop zone in a wash deposit. Winter–spring rains flood the China Lake playa, bringing fine particles with water runoff from surrounding hills. Thunderstorm runoff may similarly renew the fine particle fraction of soil in the Los Angeles wash at Yuma. The precise source locations of the other desert soils obtained in Saudi Arabia and Israel are not known, but both of these specimens are dominated by near spherical particles, with most of the mass confined to the 0.125<D>0.250-mm size range. These are very old

Figure 1. Photomicrograph of a bulk (unsieved) specimen from the Natick drop test pit. Very few smooth particles are present. Several of the particles are sodium chloride crystals, according to EDAX analysis.

desert soils, smoothed by drifting and apparently near winnowing equilibrium. "New" fines are generated in these old soils through diminution and polishing of the larger particles during drifting and other wind induced motion.

The soils from the several drop zones in the southeastern U.S. (Camp Blanding, Fort Benning, Fort Bragg) are quite similar in size distribution, containing about one-half the relative mass of particles passing the 0.125-mm sieve as the other samples. It should be noted that several of these contain fines agglomerated onto the larger members of the population, which can be dispersed by some energetic disturbance.

The soil specimen from the Natick test pit contains nearly as much mass passing the 0.125-mm sieve as the Yuma and China Lake specimens. This specimen is somewhat unusual, as it contains some small sodium chloride crystals that are readily apparent as shown in the photomicrograph in Figure 1. Comparison of the fraction of the soil passing the 0.125-mm sieve in the test pit with that removed from within a section of flat coreless braid exposed to that soil (braid [10]) shows that the fine particle fraction is readily exchanged through the braid during testing. This is in agreement with the conclusion of Rodier et al. (1989), that smaller particles from the western U.S. desert test sites reduce strength of parachute suspension cords more readily than other, larger soils. A more extensive investigation of the properties of the fraction passing the 0.125-mm sieve of the Natick and other specimens was conducted to investigate the influence of particle size on fiber degradation.

Microscopic examination of soil material extracted from within braid and core of tested suspension lines

The scanning electron microscope examination of soil particles contained within braid and core strands of suspension lines subjected to soiling in the Natick test pit by Goode (1989) indicates that these particles are less than 50-µm in their greatest dimension. A specimen of acrylic-coated, flat, coreless polyester braid, which had been exposed to numerous drop and soiling cycles, contained an obvious internal store of this material. A 6.3-cm-long section of this braid, adjacent to a lock ring, was cut apart for analysis, and contained 1.311 g of entrapped grit (specimen braid [10] in Table 2). A small amount of the fraction of braid (10) that passed the 0.125-mm sieve was aerodispersed onto a glass slide for size analysis, which was done microscopically, using the Porton technique and shadowgraphic substage illumination. A similar size analysis was performed on the fraction of the Natick (03) sample that passed the 0.125-mm sieve. A comparison of size distributions is given in Figure 2.

The particles constituting the braid (10) sample were removed from the inside of the braid by kneading, tapping and shaking the cord. Two seg-

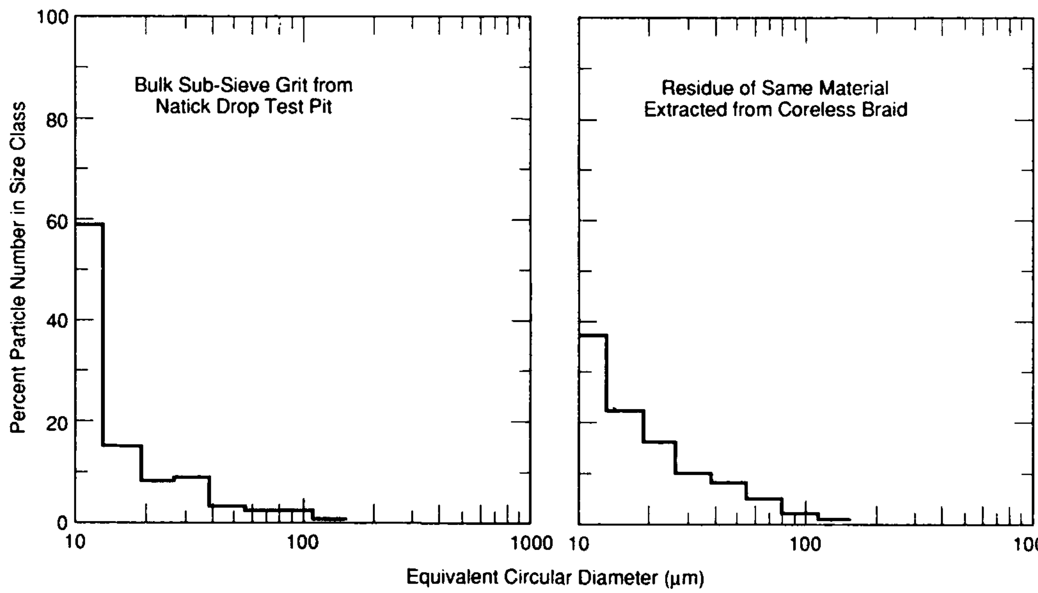


Figure 2. Size distribution of bulk soil from the Natick drop test pit, and of the fraction of this soil that infiltrated a flat braid test specimen. The size distributions were obtained microscopically from mechanically dispersed specimens and represent the fraction of particle number in each size class (sub-sieve is the portion passing the 0.125-mm sieve).

Figure 3. Photomicrograph of the interior of a segment of flat braid subjected to 84 test drops in the Natick test pit. Note that particles of maximum dimension, comparable to individual strand diameters, are retained among the strands and that smaller particles adhere to the individual strands.

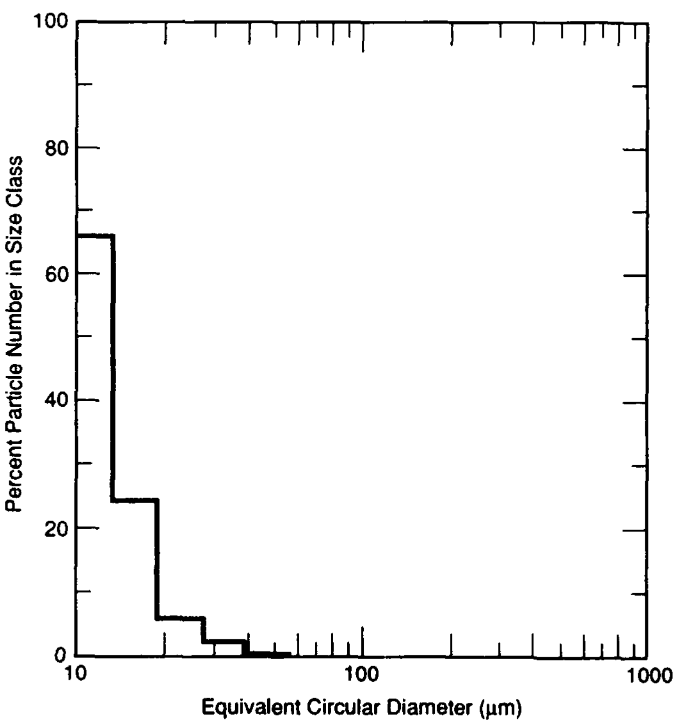


Figure 4. Size distribution of particles washed from the braid specimen in Figure 3 following the mechanical extraction processes used to obtain the material described in Figure 2.

ments of the braid were cut from the original, after no more particles could be removed. One segment was slit lengthwise and mounted for scanning electron microscope analysis of the internal fibers. Some representative particles retained within the braid are shown in Figure 3. The second segment was placed in a small vial with 5 mL of distilled water and vigorously shaken. A microliter sample of the dispersion was removed and mounted for microscopic examination. The size distribution of the particles in this water dispersion is shown in Figure 4.

The size distribution of the particles retained within the fibers of the braid is not directly comparable to the size distribution of the bulk material or that mechanically removed from the braid, as the water dispersion may be more effective in breaking up small particle aggregates. The size analysis and SEM analysis do verify the earlier SEM analysis of Goode (1989), and indicate that fine particles of less than 30-µm diameter are retained within the fiber bundles. These finer particles should be considered as major contributors to suspension cord degradation.

A second suspension cord was analyzed to estimate the degree of soiling necessary to contaminate the interior of braid. A 15-cm section was cut from a cord sample (designated 7A in the Natick series), which had been subjected to a single contamination and dynamic load cycle. The same mechanical means were used to extract particles from the braid as were used with the previous sample, but the amount of material collected from the braid was well below detection limits. The braid and core were then transferred to small vials with 5 mL of distilled water and shaken vigorously. A noticeable fine particle turbidity was immediately present in the vial containing the core strands, but a slight solubility of the dye coloring the braid masked the turbidity in this case.

Microscopic examination of soil specimens

The previous analyses show that the fine fraction of soil particles, which constitute a minor part of the mass of most of the training ground and test soils provided, are retained within suspension cord. An additional microscopic size analysis was conducted on some of the soil specimens to examine the fine particle contamination potential. The size analyses differ in that the relative mass of material passing a given mesh but being retained on the next mesh makes up the sieve size fractions; the microscopic analysis reports the relative number of particles greater than a specified equivalent area (circle size) but less than another. The two methods report a relative pure number ratio as a function of size class, and so can be displayed on the same axis. The number N and mass M are related through

$$\Sigma M = \Sigma N_i \, (f\,[D_i])$$

in the case of uniform particles, but shape and density may vary with size (Hinds 1982) in natural materials.

The microscope analyses were conducted by placing a glass slide coated with GE SR 516 silicon adhesive beneath the 0.125-mesh final stage of the DIN Prufsieb sieve series. A few milligrams of the smallest size fraction was resieved, allowing the sieve series to disperse the sample to produce a uniform dispersion on the slide. This dispersion mimics mechanical dispersion but may not thoroughly disperse chemically bound aggregates, or those smaller than the 10-µm diameter.

The size analyses were conducted at 50× magnification, which provides a minimum resolvable particle size class of 10–14 µm that is consistent with the dispersion technique. The Yuma and Natick specimens seemed to disperse quite well with this method. These specimens were analyzed again at a magnification of 110×, providing resolution of the 3.5- to 5.0-µm size class, to facilitate examination of the fine fraction, considering the Rodier et al. (1989) observation that western desert test site exposure was more damaging to suspension cords than other sites.

A comparison of the frequency of occurrence of particles with respect to diameter of the Yuma and Natick Test Pit soils is given in Figure 5. Although the maximum frequency of particles in the Natick soil occurs in a class only one interval larger than that of the Yuma specimen, the count median diameter from Natick (22 µm) is nearly twice as large as that for Yuma (11.5 µm). The area-to-mass ratio of the particles increases as median diameter decreases, the Yuma material has a much greater potential for abrasion if it is well dispersed.

Microscopic examination of the soil specimens indicated that, in several cases, soil particles retained by the DIN Prufsieb sieve series were coated by much finer particles. This was especially apparent in the Fort Bragg and China Lake specimens. Particles of 30 µm or larger diameter are easily dispersed and mobilized by mechanical or ventilation processes, and easily deposited on any available surface. Fine particles of the smaller, more damaging size range may be co-deposited upon

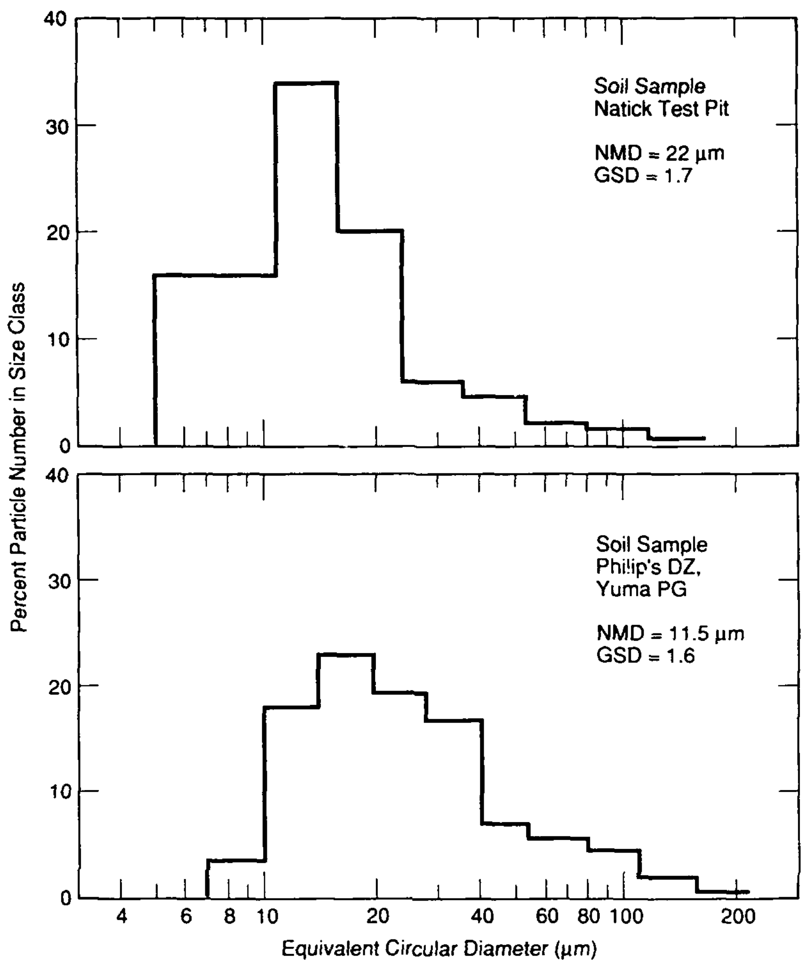


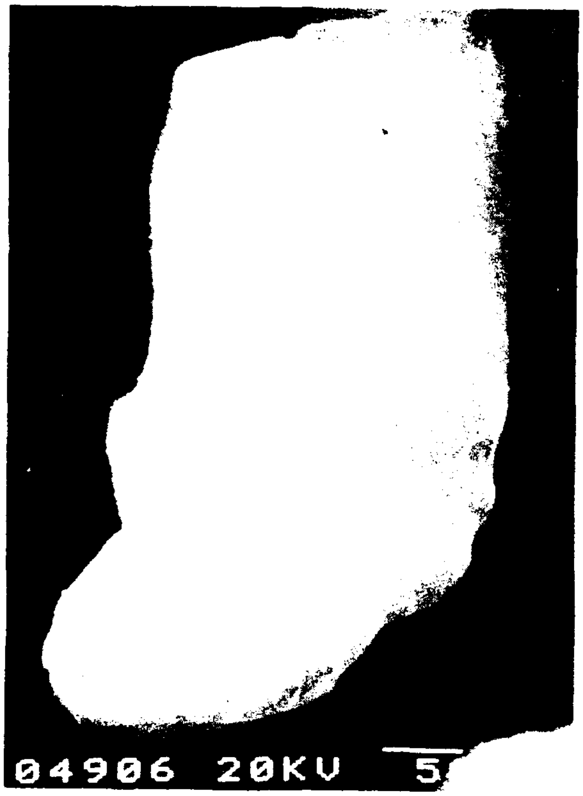
Figure 5. Comparison of the frequency of occurrence of particle diameters in the size range passing the 0.125-mm sieve of specimens from the Natick test pit and Yuma Proving Ground.

suspension cords as part of the large agglomerates and transferred to the cord material when the larger fraction is redispersed in the hanging, shaking, inspection and repacking process.

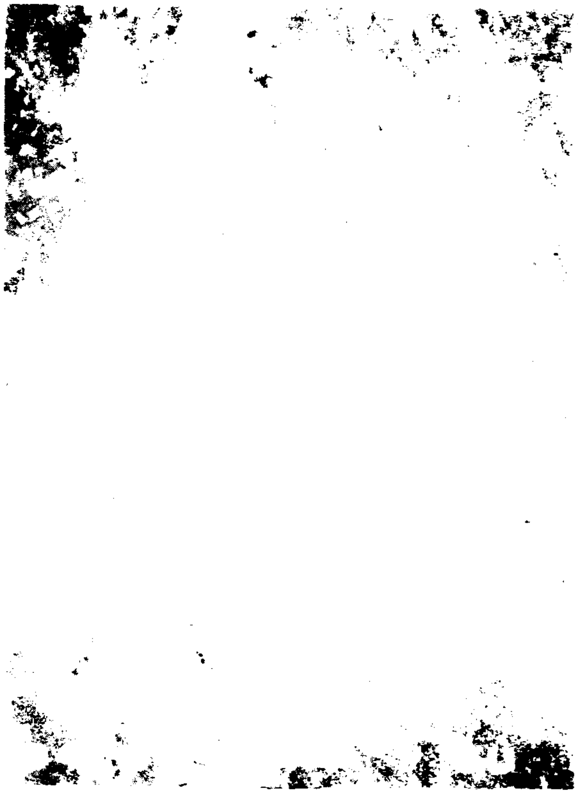
Some of the specimens contained small particles of apparently different composition, tightly agglomerated on the surface of larger particles. These were examined by scanning electron microscopy. Figure 6 shows three SEM analyses of a particle from the Normandy (06) drop zone at Fort Bragg. Figure 6b indicates the presence of numerous particles less than 5 µm diameter adhering to the surface of the larger particle. Figure 6c shows the fine particle field at high magnification and includes individual particles of sub-micrometer diameter. These small particles will have the properties of the large particle while aggregated with it; however, if an energetic dispersion mechanism frees them from the surface they will recover their original properties. A similar analysis of fines, agglomerated with a larger particle from the Holland (06) drop zone at Fort Bragg, is shown in Figure 7.

Microscopic analysis of other soil specimens

Additional microscopic size analyses were obtained for some other specimens. These are plotted along with the sieve size distributions in Appendix A. The most interesting of these is the sample obtained along the Riyadh–Dhahran highway in Saudi Arabia. The sieve analysis of this material shows most of it to be in the $0.125<D>0.250$-mm sieve class. Microscopic analysis of the fraction passing the 0.125-mm sieve shows almost 0.70 of this material to be smaller than 14 µm in diameter. The Israeli soil has similar properties but was not formally counted, and the material from Sicily (04) drop zone at Fort Bragg contains more than 0.50 of



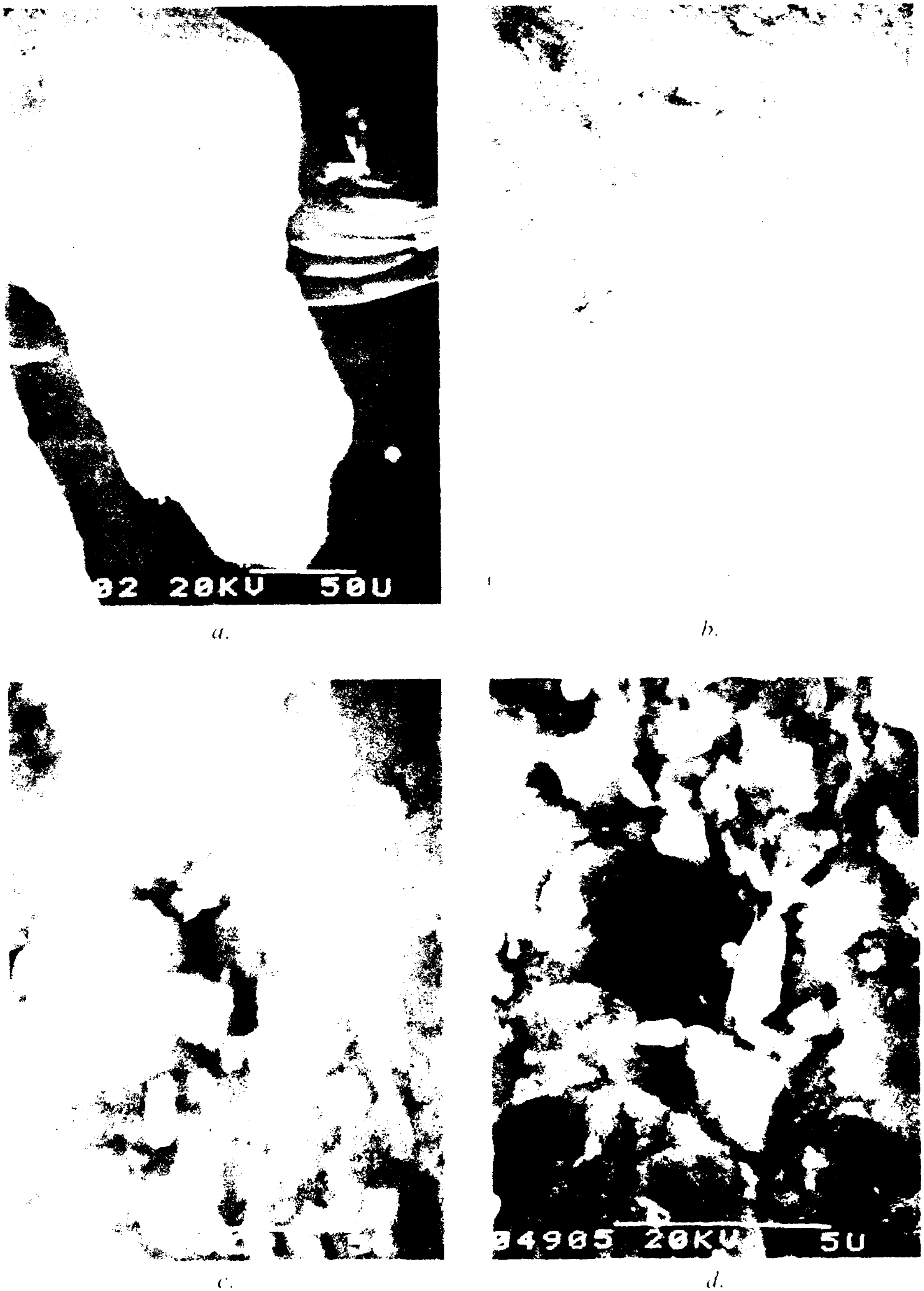
a. Low magnification.



b. 20× higher than Figure 6a.

c. High magnification.

Figure 6. Photomicrographs of a single particle from Normandy (06) drop zone, showing the population of smaller particles attached to the particle's surface.



a. *b.*

c. *d.*

Figure 7. Photomicrographs of a particle from the Holland (05) drop zone showing the fine particles agglomerated upon the the surface of the larger individual.

particles less than 14 μm in diameter. Because of the difficulty in properly dispersing particles less than 10 μm in diameter, the cuts passing the 0.125-mm sieve from all specimens were analyzed for clay mineral content by the University of North Carolina Soil Sciences laboratory (Appendix A).

Examination of dust fall in parachute riggers' lofts

Metal plates similar to the Diem "haftfolie" (Hogan 1972) were prepared and mounted in 4 × 5 film holders for transport and exposure to dust fall, for various periods, in the vicinity of active parachute riggers' tables.* The plates were retrieved, and the central area examined. An SEM photo of a plate exposed at Fort Bragg is shown in Figure 8. The particles collected are larger than those found within suspension lines. It would be expected that the hanging, shaking and inspection procedures used in rigger's lofts would be most effective in dislodging large particles from the surface. It is possible that these procedures remove a portion of the finer particles, but that loft ventilation, and the slower fall speed of the fines, reduced the collection efficiency of these on the sampling plates. It may be worthwhile to re-examine this operation in a systematic experiment, and to evaluate the effectiveness of silicon and fluorocarbon finishes for mechanically releasing surface particles.†

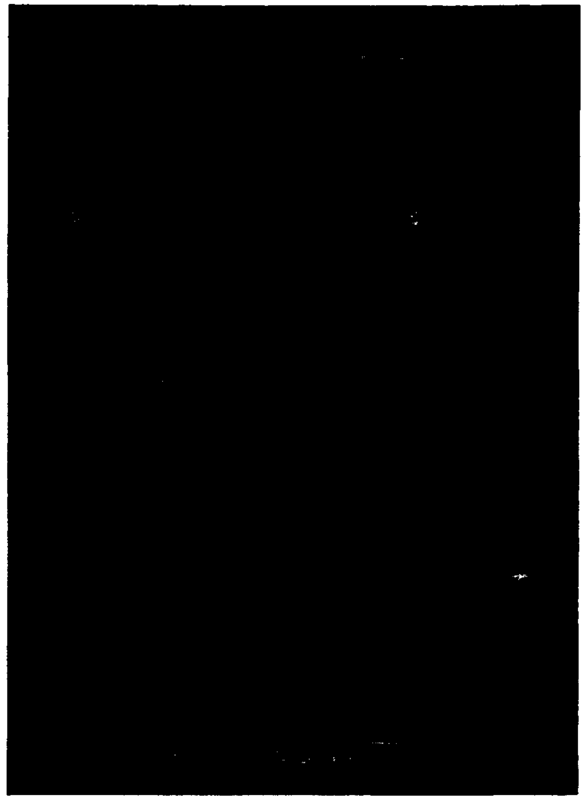


Figure 8. Photomicrograph of particles precipitated to a test plate in a riggers' loft at Fort Bragg.

Examination of the effective hardness of soil specimens

Several 50-mm-diameter delrin disks (delrin is an acetal resin with strength and hardness similar to nylon) were machined from bar stock. Small quantities of sieve-classified soil were transferred to a disk surface and another disk was placed atop the specimen. Light pressure was applied and the disks moved in contact for about 5 mm. The disks were separated and examined for striations by incident light microscopy. This is a different approach than that of Hall (1989), who mounted the soil particles within a matrix, and examined individual particle resistance to scratching by a hardness testing point.

Both of these techniques raise questions, rather than provide conclusions, because the largest particles produce the greatest visible damage. Goode's SEM analysis of failed suspension lines, the conclusion of Rodier et al. (1989) that desert soils are more damaging to suspension lines, and this analysis of particles contained within braid and core indicate that the fine particle fraction is most damaging. Fine particles within a soil specimen may be wind or water borne allochthonous material, or may be locally produced through weathering of native soil material. It appears that it will be necessary to isolate smaller classes within the fraction passing the 0.125-mm sieve to determine the effective hardness of the fine particles. This may facilitate establishment of hardness criteria, or a size/hardness index that can be used to estimate the potential for abrasive damage by soil.

Micro-hardness measurements usually employ a stylus of known hardness that is used to mark the surface of the unknown specimen. The work reported in previous sections indicates that particles of less than 30 μm diameter are responsible for the braid and cord abrasion observed. The physical properties of particles in this size range may vary, even though the chemical composition of them may seem quite similar. It seems that a micro-scale technique capable of simultaneously examining

* By CW3 B. Riggiens, and SSG G. Moore, research coordinators from Natick RDEC.

† Personal communication with E.A. Wuester, U.S. Army Natick Research, Development and Engineering Center, 1991.

the hardness of a large number of similarly sized particles would be most desirable to examine the range of hardnesses encountered. It may be possible to apply the Mohs technique on a micro-scale to examine the hardness of a field of particles. Two Mohs hardness standards could be used to sandwich a monolayer of size-classified particles. Relative motion of the Mohs plates would produce scratches indicative of the relative hardness of the particles as compared to the plates.

An additional approach might also be used. Fine particles could be dispersed on a Mohs substrate. A fiber could be pulled across the surface, causing sufficiently hard particles to imbed in the fiber. Continued motion of the fiber would deform the Mohs substrate if it is softer than the fiber–particle aggregate. This might provide an abrasive index for the material pair.

DISCUSSION

This analysis and the previous analysis by Goode (1989) of suspension cords exposed to soil and stress in the Natick test pit indicate that particles of diameter less than or equal to the size of individual strands of exterior braid are retained within the braid. These particles apparently enter the braid as openings are created during flexure, and then adhere to individual strands. The small size of the particles facilitates their adherence to the individual strands, and this, combined with small inertia, allows them to remain attached during shaking or other mechanical removal processes. The particle sizes of material entrapped within flattened coreless braid (Fed Spec T C 2754) in Figures 1, 2 and 3, when compared to the particle sizes of the bulk Natick test pit material, increase inversely with diameter to our threshold of resolution. This indicates that the braid selectively admits and retains particles with increasing efficiency as the diameter of particles diminishes. All of the soil specimens furnished contain some particles in the size range comparable to individual strands of the exterior braid of the suspension cords, but those from the U.S. desert test sites contain proportionally more. This may be attributable to replenishment of fine particles through waterborne transport in the playas and washes where the test sites are established. The Saudi Arabian and Israeli desert specimens contained smaller relative masses of fines, perhaps reflecting winnowing processes as the material weathers with time. The several specimens from training areas in the southeast U.S. may contain greater fractions of fine particles than found in this analysis. Inter-particle binding forces increase with diminishing particle diameter, and the rather mild dispersion processes used in these experiments may not have fully dispersed the fine particle fraction.

Mechanical dispersion is likely to be the major source of soiling during use of personnel parachutes, but aerodynamic dispersion by local winds enhanced by jet blast and propellor or rotor vortices may increase the overall dust mass in the air. Repeated aerodynamic dispersion in training areas may enhance the concentration of fines in near-surface soil. The greatest contamination of support lines may arise from simple flexure while in contact with a particle bed containing fines, with the repeated strand motion selectively extracting particles of size less than the temporary voids among the strands. This is a relatively gentle winnowing method and may indeed entrain more particles from the fine-enriched and easily dispersed soils of the desert test areas.

I have discussed the hypothesis that particles of diameter comparable to or less than the diameter of individual strands of the protective braid surrounding suspension cords most freely enter, and are retained within the cords. There are some tests and experiments that can be attempted to evaluate this hypothesis.

1. A water wash seems effective in removing fines from within the strands of suspension cord. Analysis of the wash by turbidometric methods would enable measurement of the degree of fine particle contamination of a statistically significant number of cords. This experiment would produce a valid soiling history if done on a collection of well-documented test or training cords.

2. A systematic flex test in which soil type or size distribution could be varied, combined with the turbidometric wash analysis, could be used to evaluate the inherent geologic soil differences on particle penetration within suspension cords.

3. The relative hardness of soil material recovered from within cord subjected to a systematic flex test should be determined as criteria for material specification.

CONCLUSIONS

This analysis and preceding microscopic analyses of parachute suspension cords find soil particles of diameter equal to or smaller than the diameter of individual fibers retained within suspension cords. It would appear, but it is not uniquely demonstrated, that the degradation of suspension

line strength is proportional to the number of fine particles imbedded per unit area of fiber surface. This degradation must also depend upon the hardness and surface area (shape factor) of the particles. I propose two avenues of additional research that may more certainly define the properties of soils that degrade suspension cord strength.

The effective hardness of soil particles and the combined abrasiveness of soil–fiber combinations might be experimentally determined through hardness comparisons of size-classified soil particles with Mohs hardness standards. This would determine if something like work hardening happens during the size diminution processes from which soils are derived from antecedent minerals. It would also provide a quantitative measure, or abrasion index, of soil–fiber pairs relative to materials of defined hardness.

The experimentally derived hardness or abrasive index should be compared with other measurable physical properties of the soil to determine if fiber degradation properties can be associated with more easily measured parameters. Measurement of polarimetric and photometric properties of hardness-classified material might be the most productive approach to a field analysis of potential degradation properties of soils.

The results of this work generally support the proposal of Rodier et al. (1989) that southwestern U.S. desert soils are more damaging to cords than those of southeastern U.S. training areas. I have begun a quantitative method to describe the degrading processes of soil particles on fibres.

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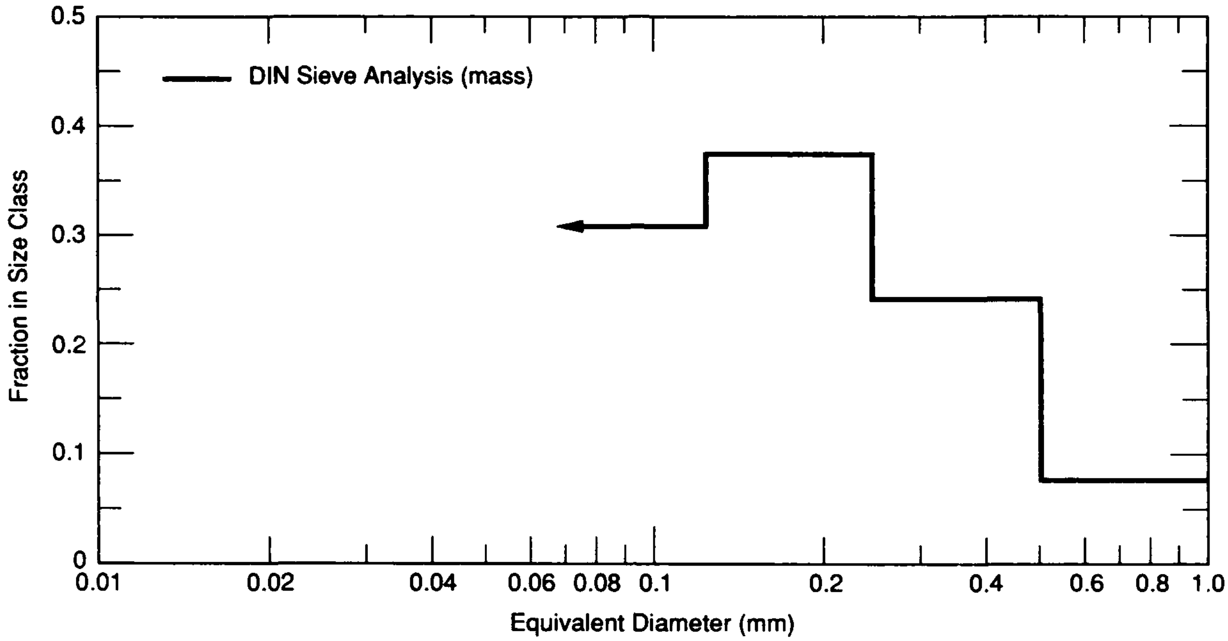
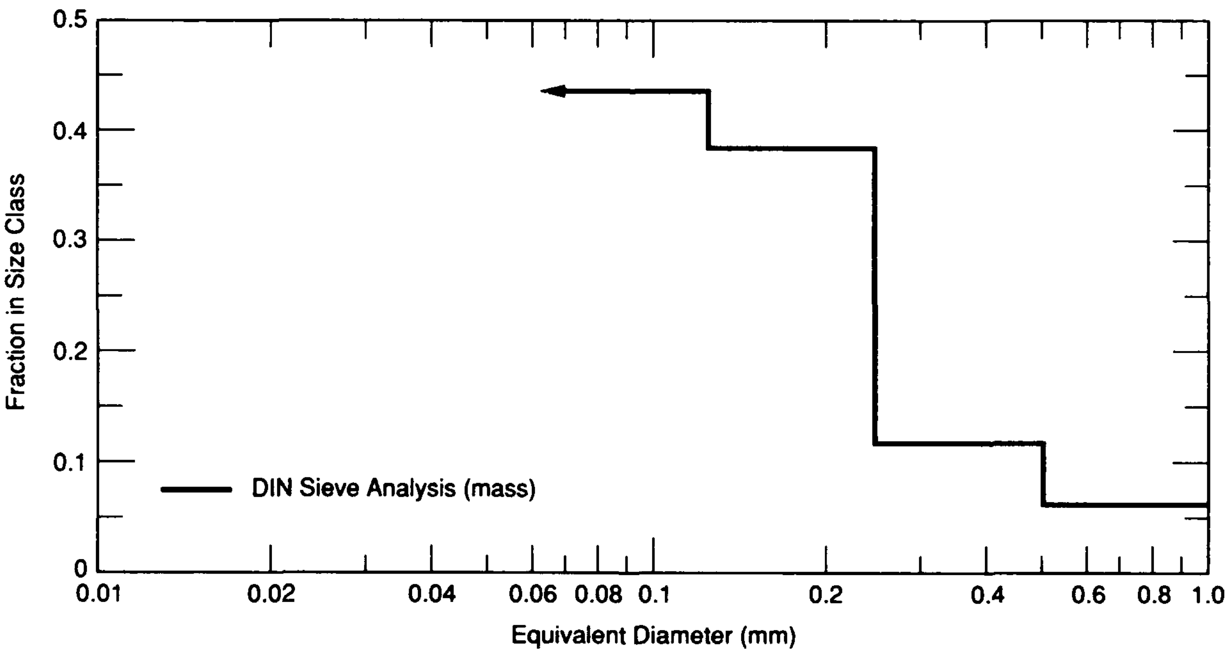
APPENDIX A: ADDITIONAL ANALYSES OF SOIL SPECIMENS

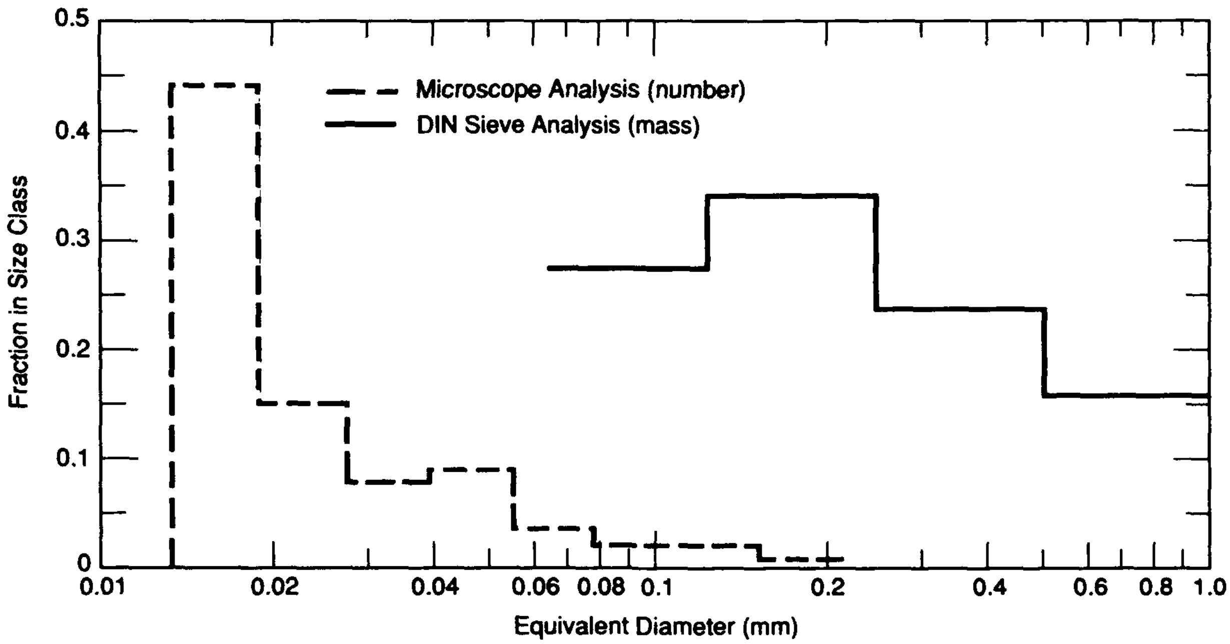


a. Yuma (01).

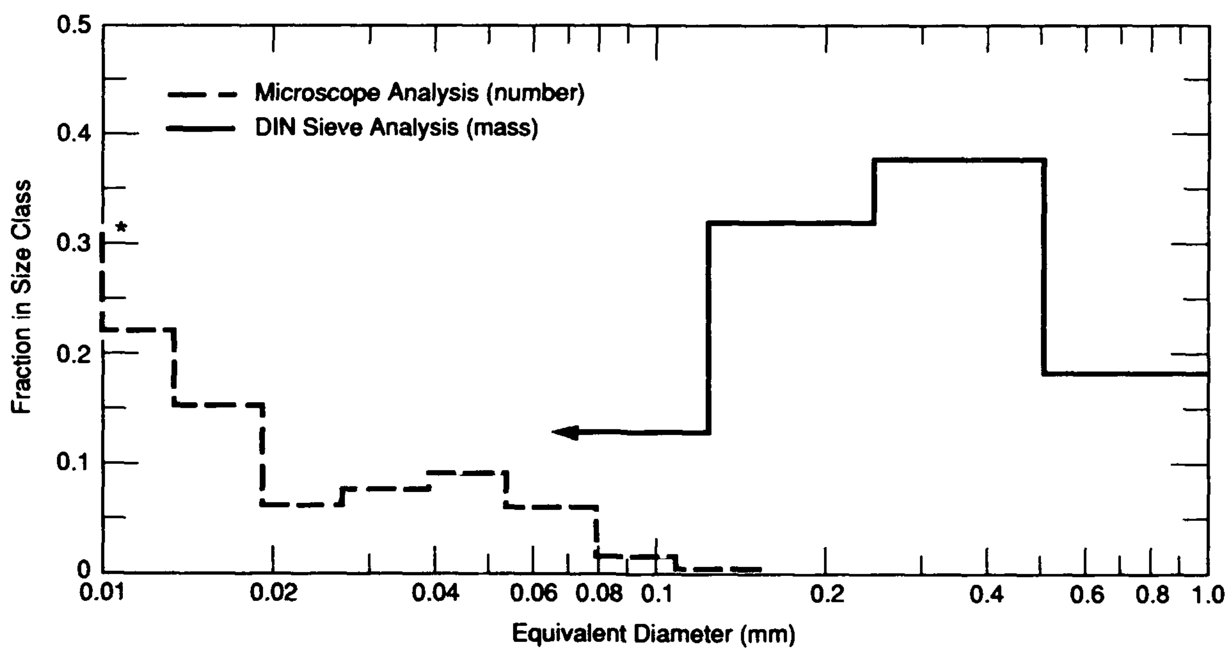


b. China Lake (02).

Figure A1. Results of sieve size analyses. These analyses are confined to particles less than 1 mm in diameter; small pebbles and bits of organic matter were removed before sieving

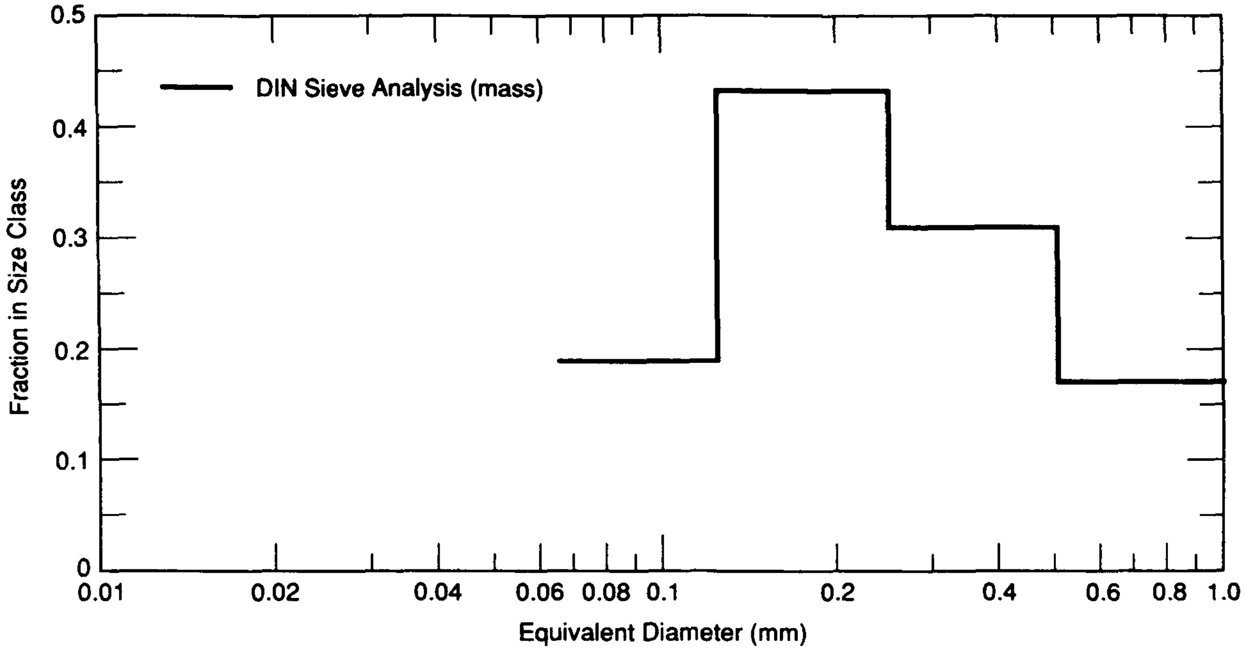


c. Natick test pit (03).

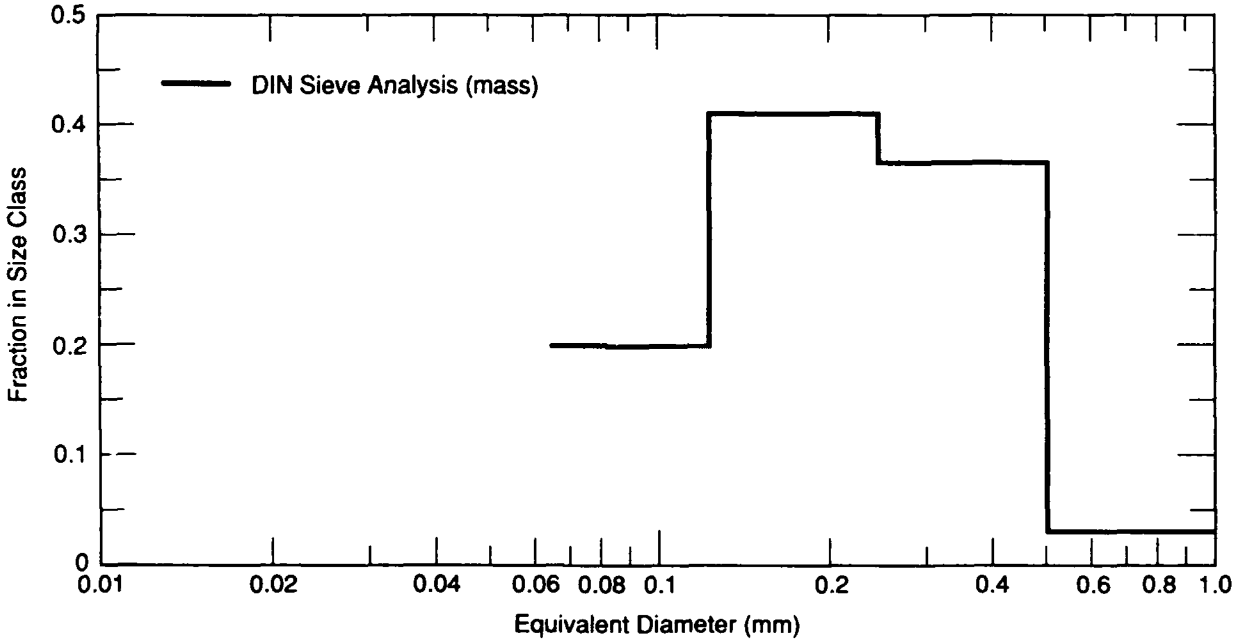


d. Sicily (04).

Figure A1 (cont'd). Results of sieve size analyses. These analyses are confined to particles less than 1 mm in diameter; small pebbles and bits of organic matter were removed before sieving.

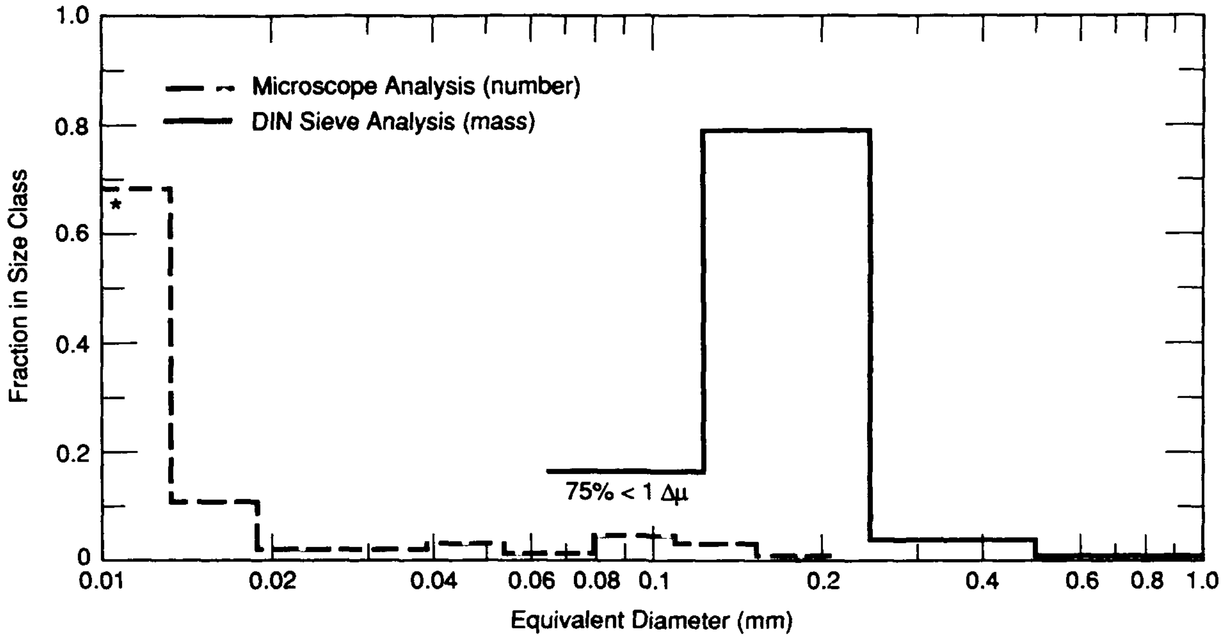


e. Holland (05).

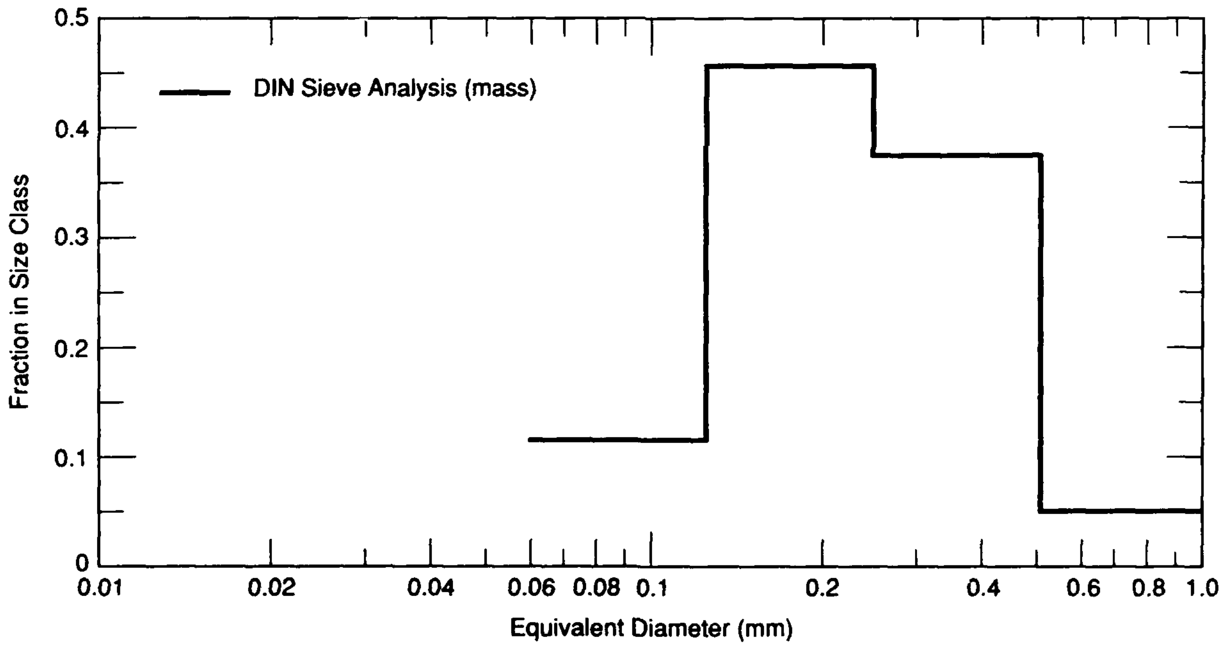


f. Normandy (06).

Figure A1 (cont'd).

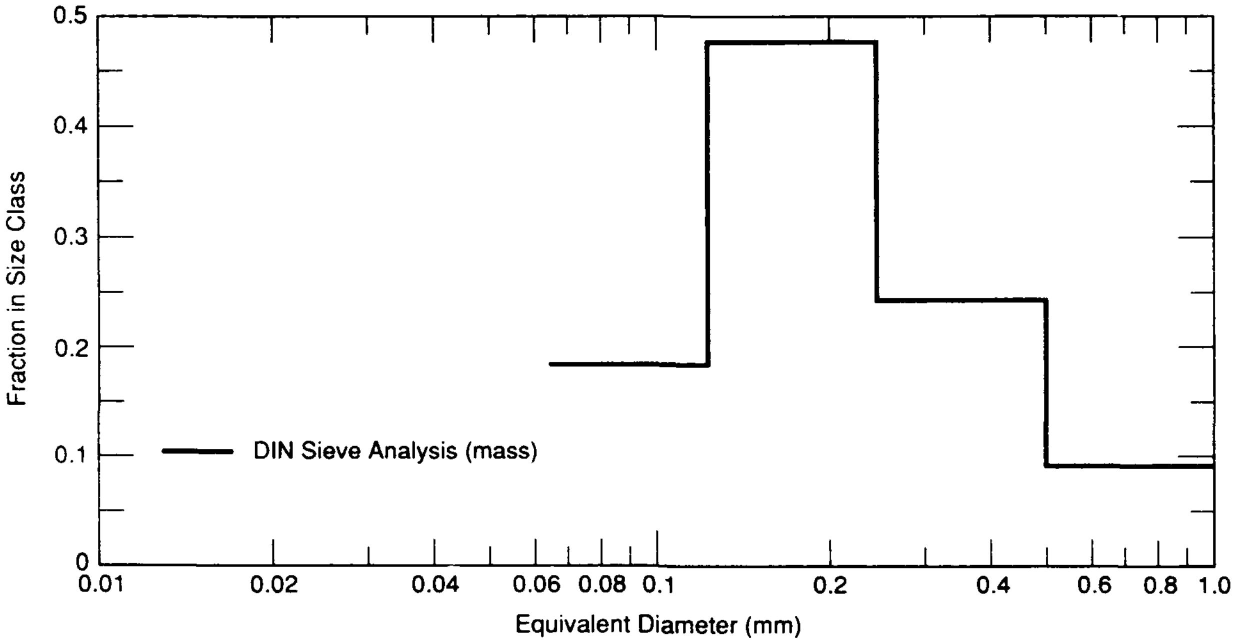


g. Saudi Arabia (07).

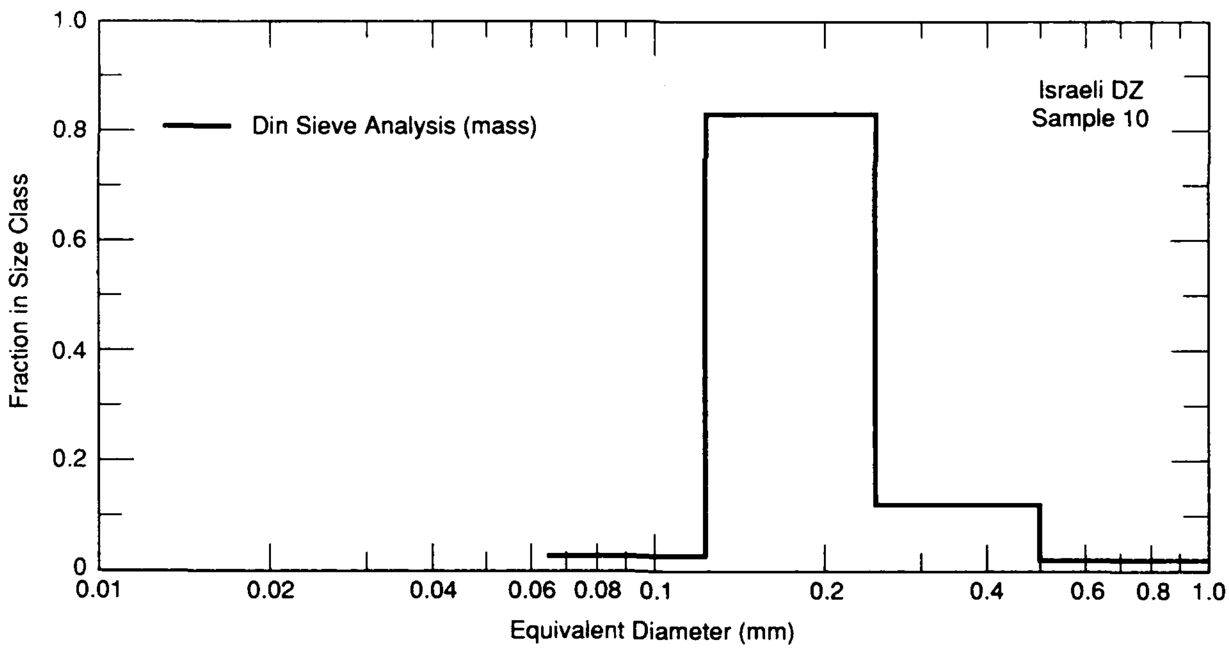


h. Blanding (08).

Figure A1 (cont'd). Results of sieve size analyses. These analyses are confined to particles less than 1 mm in diameter; small pebbles and bits of organic matter were removed before sieving.



i. Benning (09).



j. Israel (11).

Figure A1 (cont'd).

1. × 312.

2. × 163.

3. × 156.

Figure A2a. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—Yuma (01).

1. × 163.

2. × 655.

Figure A2b. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—China Lake (02).

1. × 163.

2. × 326.

Figure A2c. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—Natick TP (03).

1. × 163.

2. × 163.

Figure A2d. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—Sicily (04).

1. × 163.

2. × 163.

Figure A2e. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)— Holland (05).

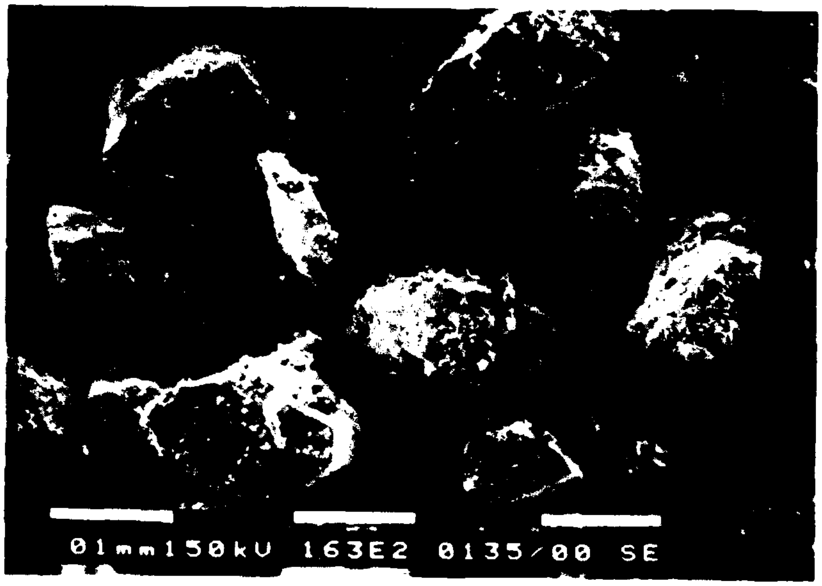
Figure A2f. Scanning electron microscope photograph of sample (by the Soils Laboratory of the University of North Carolina)—Normandy (06), × 163 .

Figure A2g. Scanning electron microscope photograph of sample (by the Soils Laboratory of the University of North Carolina)—Saudi Arabia (07), × 163.

1. ×163.

2. ×163.

Figure A2h. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—Blanding (08).



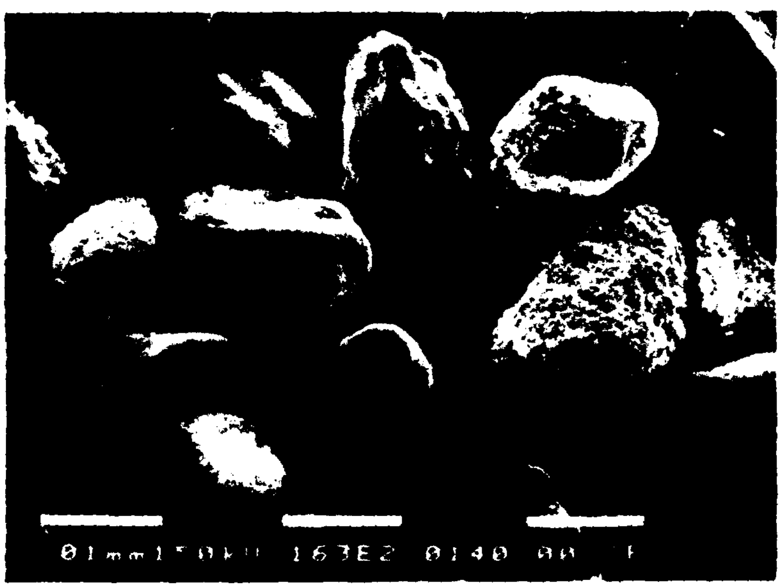
1. × 163.

2. × 163.

Figure A2i. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—Benning (09).

Figure A2j. Scanning electron microscope photograph of sample (by the Soils Laboratory of the University of North Carolina)—Braid (10), × 163.

1. × 163.



2. × 163.

Figure A2k. Scanning electron microscope photographs of samples (by the Soils Laboratory of the University of North Carolina)—Israel (11).

Table A1. Mineralogical analysis of sands (by the Soils Laboratory of the University of North Carolina).
Samples were ground with an agate mortar and pestle with 100% ethanol as the grinding medium and then dried on a glass microscope slide for XRD. Patterns were obtained using CuK radiation.

Sample	*Analysis**
01 Yuma	Quartz > feldspar = mica (weathered); sharp reflection at 3.035A not identified.
02 China Lake	Quarts > albite > hornblende> chlorite; sharp reflection at 8.46A not identified.
03 Natick TP	Halite = quartz > mica (biotite) > albite; trace of chlorite.
04 Sicily	Quartz >>> mica (trace); essentially only quartz.
05 Holland	Quartz > dolomite > calcite(?) >> mica (trace); unidentified peak at 3.025A.
06 Normandy	Quartz
07 Saudi Arabia	Quartz >> calcite > mica(?); several well-defined but unidentified peaks.
08 Blanding	Quartz; trace of vermiculite
09 Benning	Quartz; trace of feldspar.
10 Braid	Halite > quartz > mica > feldspar (albite?) > chlorite
11 Israel	Quartz >> feldspar = hornblende(?)

* Relative amounts based on XRD peak intensities; not quantitative.

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13. ABSTRACT (*Maximum 200 words*)

Soil samples, collected at proving grounds, test sites and paratroop training areas, were examined in an attempt to estimate their potential abrasive properties when in contact with parachute support lines. Portions of support lines that had been invaded by grit during strain tests were also examined to determine the properties of the particles that degraded the lines. These preliminary analyses indicate that soil particles of a size comparable to that of the individual filaments of the parachute cord infiltrate to the interior of the cord, become embedded and damage the cord. It is necessary to determine some additional soil properties, most importantly effective hardness of the individual grains, to establish a general description of performance degradation.

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